GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3503 GTRI/~~GIT~~ DATE 4/4/83

Project Director: J. A. Woody ~~School~~/Lab ECSL/ECD

Sponsor: U. S. Army Missile Command; Redstone Arsenal, AL 35898

Type Agreement: Delivery Order No. 0004 under Contract DAAH01-83-D-A013

Award Period: From 3/24/83 To 4/30/83 (Performance) 6/30/83 (Reports)

Sponsor Amount: Total Estimated: $ 15,355 Funded: $ 15,355

Cost Sharing Amount: $ None Cost Sharing No:

Title: Antenna System Development

ADMINISTRATIVE DATA OCA Contact Faith G. Costello

1) Sponsor Technical Contact:

Thomas Pierce
Systems Simulation & Dev. Directorate
US Army Missile Command
US Army Missile Laboratory
Attn: DRSMI-RER
Redstone Arsenal, AL 35898
PH: 205-876-4970

2) Sponsor Admin/Contractual Matters:

Mr. Thomas A. Bryant
Office of Naval Research
Room 206, O'Keefe Bldg.
Georgia Institute of Technology
Atlanta, Georgia 30332

Defense Priority Rating: DO-A2 under DMS Reg 1

Military Security Classification: Unclassified (general scope of work)
(or) Company/Industrial Proprietary:

RESTRICTIONS

See Attached Gov't Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category. See additional restrictions on re-budgeting travel funds: (2) C-2(f) (page 4 of basic agreement)

Equipment: Title vests with (1) B-2(c) (page 3 of basic agreement) Government; except that items costing less than $1,000 vest with GIT if prior approval to purchase is obtained from the Contracting Officer.

COMMENTS:

Send information copy of all correspondence addressed to Administrative Contracting Officer (ACO) to Commander, US Army Missile Command, Attn: DRSMI-ICDB Redstone Arsenal, AL 35898.

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GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date August 16, 1983

Project Title: "Antenna System Development"

Project No: A-3503

Project Director: J. A. Woody

Sponsor: U. S. Army Missile Command

Effective Termination Date: 4/30/83

Clearance of Accounting Charges: 6/30/83

Grant/Contract Closeout Actions Remaining:

- [X] Final Invoice ~~and Closing Documents~~
- [ ] Final Fiscal Report
- [X] Final Report of Inventions
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Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

2 May 1983

Commander, USAMICOM
Transportation Officer
M/F DRSMI-RDR
Redstone Arsenal, AL 35898

Attention: Mr. T. Pierce
DRSMI-RER

Subject: Cost and Performance Report No. 1, Project A-3503, Delivery Order No. 0004 under Contract No. DAAH01-83-D-A013, "Antenna System Development Task" covering the period from 24 March to 30 April 1983.

Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated reporting period.

Sincerely,

Jimmy A. Woody
Project Director

Approved:

H. W. Denny, Chief
Electromagnetic Compatibility Division

Enclosure

PERFORMANCE AND COST REPORT

CONTRACT NUMBER DAAH01-83-D-A013 DATE 2 May 1983 CONTRACTOR Georgia Tech - EES

CONTRACT VALUE $15,355 NO. OF LABOR HOURS 320 COMPLETION DATE (TECHNICAL REPORT) 30 June 1983

TASK/PROGRAM	Expended This Period		Cumulative To Date		% of Total L/H Spent To Date	% of Total Funds Spent To Date	Cumulative % of Work Completed	
	L-Hours	Funds	L-Hours	Funds			This Period	To Date
Antenna System Development	341	$13,722	341	$13,722	107	89	99	99

Are remaining labor hours sufficient to complete each task? Yes If not, which tasks have insufficient labor hours? ______

Are remaining funds sufficient to complete each task? Yes If not, which tasks have insufficient funds? ______

ANTENNA DESIGN AND MECHANICAL FEASIBILITY ANALYSES

By

J. K. Daher
D. O. Gallentine
W. R. Hitch
J. A. Woody

Submitted to

U.S. ARMY MISSILE COMMAND

FINAL TECHNICAL REPORT

ANTENNA DESIGN AND MECHANICAL FEASIBILITY ANALYSES

Contract No. DAAH01-83-D-A013

Delivery Order No. 0004

April 1983

By

J. K. Daher
D. O. Gallentine
W. R. Hitch
J. A. Woody

Submitted to

U.S. Army MICOM
DRSMI-RER
Redstone Arsenal, AL 35898

Prepared by

Electromagnetic Compatibility Division
Electronics and Computer Systems Laboratory
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

(A Unit of the University System of Georgia)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

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		6. PERFORMING ORG. REPORT NUMBER A-3503-F
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18. SUPPLEMENTARY NOTES

MICOM Project Engineer: T. C. Pierce

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Antennas
Antenna Design
Antenna Evaluation

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This program was performed to identify and define the mechanical requirements of a prototype antenna configuration. Design analyses were conducted to determine the impact of the mechanical requirements on the design of a prototype configuration. The mechanical requirements and constraints were defined for an interface adapter, base-loading coils, folding ground radials, and tunable (adjustable) radiating elements. The results of these analyses indicate that the proposed antenna configuration is mechanically feasible and prototypes should be fabricated and evaluated.

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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

PREFACE

The work described in this report was performed by personnel of the Electronics and Computer Systems Laboratory and the Electromagnetics Laboratory of the Georgia Tech Engineering Experiment Station. This program was sponsored by the United States Army Missile Command (MICOM) as Delivery Order No. 0004 under Contract No. DAAH01-83-D-A013. The program was monitored by Mr. T. C. Pierce of MICOM. The described work was directed by Mr. J. A. Woody, Project Director, under the technical supervision of Mr. H. W. Denny, Chief of the Electromagnetic Compatibility Division. This report summarizes the objectives, activities, and results of an investigation to analyze the mechanical design and feasibility of a proposed antenna configuration which was evaluated electrically on Delivery Order No. 0063 under Contract No. DAAH-81-D-A003.

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LIST OF FIGURES

ANTENNA DESIGN AND MECHANICAL FEASIBILITY ANALYSES

This report describes the significant findings of the second phase of a program to develop a prototype antenna configuration which is simpler, lighter, and less costly than an existing antenna system. The objective of this delivery order was to identify and define the mechanical requirements of the prototype antenna configuration. A design analysis was undertaken in order to assess the impact of the mechanical requirements and constraints on the proposed antenna design. Information for this analysis was obtained during a trip to the system integration contractor's facility. This delivery order is a follow-on to Delivery Order No. 0063 issued under Contract DAAH01-81-D-A003, in which the electrical performance of the proposed antenna and selected modifications were evaluated.

On 15 March 1983, Mr. E. E. Johnson of MICOM and Mr. W. R. Free, Mr. D. O. Gallentine, and Mr. J. A. Woody of Georgia Tech visited with Raytheon personnel at the Raytheon Bedford Plant. The purpose of this visit was to discuss the mechanical and electrical characteristics of both the existing and proposed antenna configurations. The areas discussed include: the effect of the lightning and electromagnetic pulse (EMP) suppressors on the antenna's performance; the appropriate locations for mounting the lightning suppressor; methods for stowing and erecting the antenna which satisfy clearance requirements; the mechanical strength requirements of the proposed antenna configuration; the method of specifying the base-loading coil for production procurement; the method of tuning the radiating element of the antenna and the effects of the environment on the tuning mechanism; and the effects of height on the antenna. The details of the discussions and the conclusions reached during the visit are contained in the trip report given in Appendix A.

A mechanical design analysis was conducted to identify and define the mechanical requirements of the proposed antenna configuration. The impact of these mechanical requirements on the design of the prototype configuration was assessed. The mechanical requirements and constraints were defined for:

- the interface adapter,
- the base-loading coil,

- the folding ground radials, and
- the tunable (adjustable) radiating element.

The details of the mechanical design analysis are given in Appendix B. The results of this design analysis reveal no mechanical difficulties which will prohibit construction and use of the proposed antenna configuration.

In order to obtain additional design information necessary for a determination of the mechanical requirements of the prototype antenna, selected electrical measurements were performed. Antenna measurements were made to: (1) experimentally verify that a zero degree ground radial decline angle improves the gain characteristics of the antenna (as was analytically predicted under Delivery Order No. 0063), (2) determine if interchanging "off-the-shelf" base-loading coils has any effect on the antenna performance, and (3) to determine if a fixed ground radial length could be used to cover the frequency range of interest and, if so, what the optimum length of these radials should be. The measurement results and conclusions are detailed in Appendix C. In summary, it was found that decreasing the ground radial decline angle from 15 degrees to zero degrees results in approximately 1 decibel improvement in the antenna gain (at zero degrees elevation angle relative to horizontal). Therefore, a zero degree decline angle will be incorporated into the prototype antenna design. It was also determined that interchanging the base-loading coil of the original monopole, which was tuned to 88 MHz, with the base-loading coil from a monopole tuned to 78 MHz, had no discernable effect on the gain characteristics at 79 MHz. And finally, it was concluded that a fixed ground radial length of 36 inches was sufficient for use over the 68 to 88 MHz frequency range.

In summary, a program was conducted to analyze the impact of the mechanical requirements on the design of a prototype antenna configuration. It is concluded that the proposed antenna configuration is mechanically feasible and it is therefore recommended that two (2) prototype antennas be fabricated and evaluated.

APPENDIX A

Trip Report

Visit With: Raytheon Personnel

Firm or Agency: Raytheon Missile Systems Division

Address: Hartwell Rd., Bedford, MA 01730
and 350 Lowell St., Andover, MA 01810

Telephone: 617-274-7100 x2674

Date: 15 and 16 March 1983

By: Jimmy A. Woody

Project: A-3442 Distribution: File, WRF, JKD, DOG

On 15 March 1983, E. E. Johnson of MICOM and W. R. Free, D. O. Gallentine, and J. A. Woody of Georgia Tech visited the Raytheon Bedford Plant to discuss the electrical and mechanical characteristics of both the existing and proposed antenna configurations. The meeting attendees are listed in Attachment 1.

First, Georgia Tech personnel gave a presentation describing the objectives, technical efforts, and results of the Antenna Evaluation Program. On this program, the performance characteristics of one antenna configuration and nine modified configurations were evaluated. A major conclusion of this effort was that a simpler, lighter, and less costly replacement for the existing antennas is feasible and can provide comparable or better performance characteristics. Also, it was concluded that the antenna must be tunable (i.e., the length of the monopole radiating element must be adjustable) to operate properly over the desired frequency range.

Following the presentation, considerable discussions ensued regarding various electrical and mechanical aspects of the proposed antenna configuration. The areas discussed included:

- Effects of the required lightning suppressor on the antenna's performance,
- Appropriate locations for mounting the lightning suppressor,
- Effects of the required EMP suppressor on the antenna's performance,
- Method of specifying the base-loading coil for production procurement,
- Method of tuning the radiating element of the antenna,

- Effects of the environment on the tuning mechanism,
- Mechanical strength of the proposed antenna configuration,
- Methods of stowing and erecting the antenna, and
- Effects of height on the antenna's performance and access.

As a result of these discussions, it was concluded that a 2-foot adapter section for mechanically interfacing the antenna to the existing mast must be designed. (Some specifics of the design were discussed in detail.) The lightning suppressor should be mounted on the adapter section and its effects on the antenna's performance should be investigated. It was pointed out that the EMP suppressor has negligible effects on the VSWR of the antenna across the frequency range of interest.

At least two alternatives exist for specifying the base-loading coil at the time of procurement: (1) specify an "off-the-shelf" coil for a 5/8-wavelength monopole or (2) specify the exact design of the coil. In order to select the best alternative, it was decided that the effects of interchanging "off-the-shelf" coils need to be investigated.

The antenna tuning mechanism and its resistance to the environment (salt, wind, ice, etc.) were discussed. Primary concerns are the ease with which the antenna can be quickly retuned and the clearances when the antenna is lowered for retuning. These factors influence the lengths of the adapter and the tuning mechanism. Preliminary decisions on how to fabricate the tunable element and on how to provide indications of the tuned frequencies were also made. The specific details of the design need to be formulated.

The mechanical strength of the various parts of the antenna, especially the base-loading coil and connections to it, were discussed. The strength of the antenna in high winds under icy conditions is important. It was recommended that the mechanical strength of the proposed configuration be analyzed.

During the meeting, concern regarding the effects of the antenna height on performance were expressed. The final height of the proposed antenna is determined by mechanical and human access (for retuning and stowing) constraints. Since this height is somewhat lower than the height of the existing antenna, the effects of height on the antenna's performance should be determined.

The effects of an asymmetrical ground plane, below the antenna but above earth, on the azimuth pattern were questioned. These effects also need to be evaluated.

Finally, the techniques for folding the ground radials and stowing the entire antenna were discussed at length. It was decided that the radials would be hinged at the base of the antenna and would fold up around the radiating element for stowage. It was proposed that a strip of hook-and-loop fastener be attached to the end of one radial such that the radials can be secured in the stow position. The specifics of the radial's mounting, lock-down mechanism, and fastening technique in the stow position must be designed. During the discussions, it was decided that the entire antenna assembly will be stowed in a tube mounted on the side of the existing mast.

On 16 March 1983, E. E. Johnson, W. R. Free, D. O. Gallentine and J. A. Woody visited the Raytheon Andover plant. During this visit, a tour of the plant was provided. The existing antenna, mast, and complete installation were examined.

At both locations, the Raytheon personnel were extremely helpful and encouraging throughout the discussions. Based on the response at this first meeting, it is expected that future working relationships will be very good.

ATTACHMENT I

15 March 1983

DLT WHIP ANTENNA MEETING

Donald O. Gallentine	GA Tech - EES	404-894-3308
David W. Shuford	CAS, Inc.	205-837-3903
E. E. Johnson	PMO	742-3530
William R. Free	GA Tech - EES	404-894-3535
Marvin Richman	Equip. Div. PMO	617-443-9521 x 3467
David Carey	Raytheon MSD PMO	617-272-7100 x 2674
James McCulley	Raytheon MSD PMO	617-274-7100 x 3666
Philip Healey	Raytheon ESL	617-443-9521 x 2215
Robert McGurrin	Raytheon MSD PMO	617-475-5000 x 3053
Jimmy A. Woody	GA Tech - EES	404-894-3533
E. Arsenault	Raytheon MSD PMO	617-475-5000 x 3053
F. Bowen	Raytheon MSD MSL	617-274-7100 x 4889
J. DiPrima	Raytheon MSD MSL	617-274-7100 x 4889

APPENDIX B

Mechanical Design Analysis

This appendix describes the design analysis which was undertaken to identify and define the mechanical requirements of the proposed antenna configuration. Specific areas which were addressed during this analysis included the following:

- interface adapter,
- base-loading coil,
- folding ground radials, and
- tunable (adjustable) radiating element.

Figure B-1 illustrates the overall conceptual design of the antenna configuration which resulted from the design analysis. The specific details of the design are discussed in the following paragraphs.

The adapter for mechanically interfacing the antenna to the existing lower mast was designed as illustrated in Figure B-2. The length of this interface adapter was selected to be two feet, which decreases the antenna height a sufficient amount to provide clearance when the antenna is lowered and to provide easy access for retuning the antenna. The final design provides for mounting and interconnecting the lightning suppressor and for grounding the antenna. In short, a structurally sound interface adapter has been designed which meets all the necessary mechanical and clearance requirements.

The mechanical design analysis of the base-loading coil includes the type of coil to be used, the method of mounting it to the interface adapter, and its mechanical strength. It is proposed that commercially-available coils, normally used in conjunction with amateur radio monopole antennas, be used in the prototype antennas. One such coil is that manufactured by Antenna, Inc. (Model No. Exp. 1244A). The base-loading coil will be mounted to the interface adapter via a machined bulkhead-mount type N connection. The top of the coil is mounted to the radiating element with a 3/8-inch diameter, threaded connection. The design analysis indicated that the base-loading coil and connections to it are potential weaknesses and, therefore, it is recommended that actual destruct tests be conducted in order to quantify the maximum shear and moment loads.

The design of the folding ground radials resulted in an approach which includes solid stainless-steel radials hinged at the top flange of the

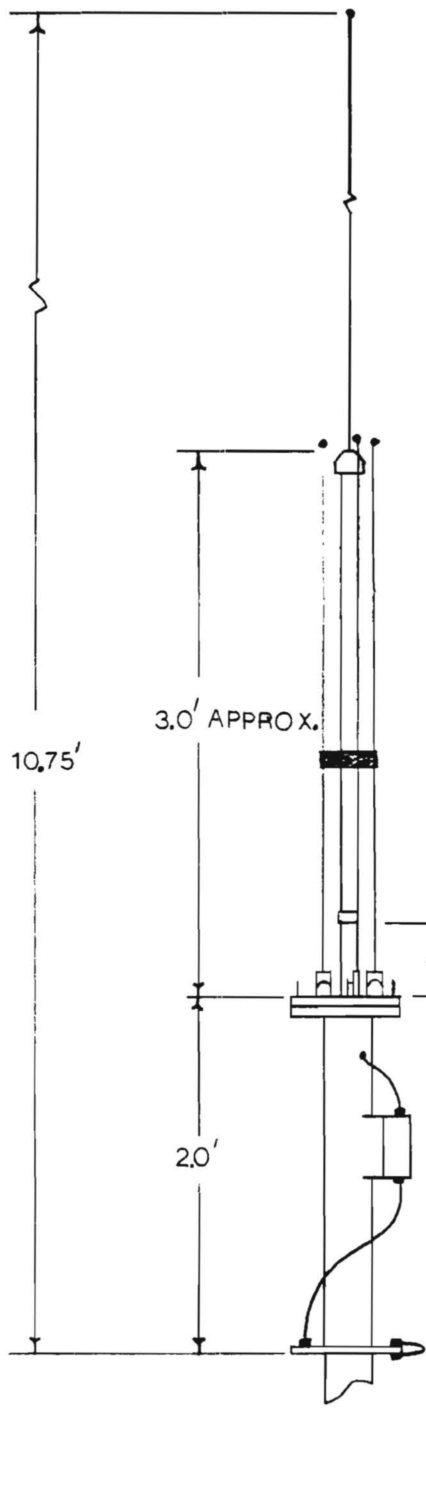

Figure B-1. Overall Conceptual Design of the Antenna Configuration.

interface adapter which allow them to fold up around the radiating element for stowage. A lock-down mechanism, which is illustrated in Figure B-2, was designed in order to secure the ground radials in their operational configuration. A strip of hook-and-loop fastener is attached to one radial to secure the radials in their stow position. The antenna design calls for ground radials whose diameter is smaller than that of the radiating element. Since the length of the ground radials (36 inches) is less than the length of the radiating element, they will withstand greater wind and ice loading than the radiating element.

The design for the adjustable radiating element is shown in Figure B-3. It consists of a 0.2-inch diameter, stainless steel whip section which slides inside of a 7/8-inch diameter hollow tube. (The hollow tube is 25.84 inches long and the entire radiating element is 104.92 inches long when fully extended.) The antenna is tuned by aligning a pair of engraved marks (one on the outside of the tube and the other visible through slots cut in the tube) which will be located according to frequency. Once tuned, the whip is held in place with a locking mechanism (similar to a pin vise) which is located at the top of the tube.

The final phase of the design was to analyze the stresses on the proposed antenna configuration due to ice loading and high winds. The analysis on the whip section resulted in a maximum realized shear stress of 88,175 psi under 100 mph wind conditions. Since the maximum allowable shear stress for the whip is 117,500 psi (calculated from the manufacturer's quoted material yield strength), the static safety factor is approximately 1.33 (117,500/88,175). Extended exposure to 100 mph winds would likely cause failure due to fatigue. Under 50 mph wind conditions, the thickness of ice which would provide a load equivalent to 100 mph wind conditions with no ice is approximately 0.3 inches. However, since the whip has a maximum diameter of only 0.2 inches, it is unlikely that such an accumulation of ice could occur in 50 mph winds. A similar analysis for the whip/hollow tube combination yields a static safety factor for 100 mph wind loading of greater than 2 and an equivalent ice accumulation of 1.3 inches in 50 mph winds.

In summary, the mechanical aspects of the proposed antenna configuration have been investigated and no mechanical difficulties were encountered which will prohibit its construction and use.

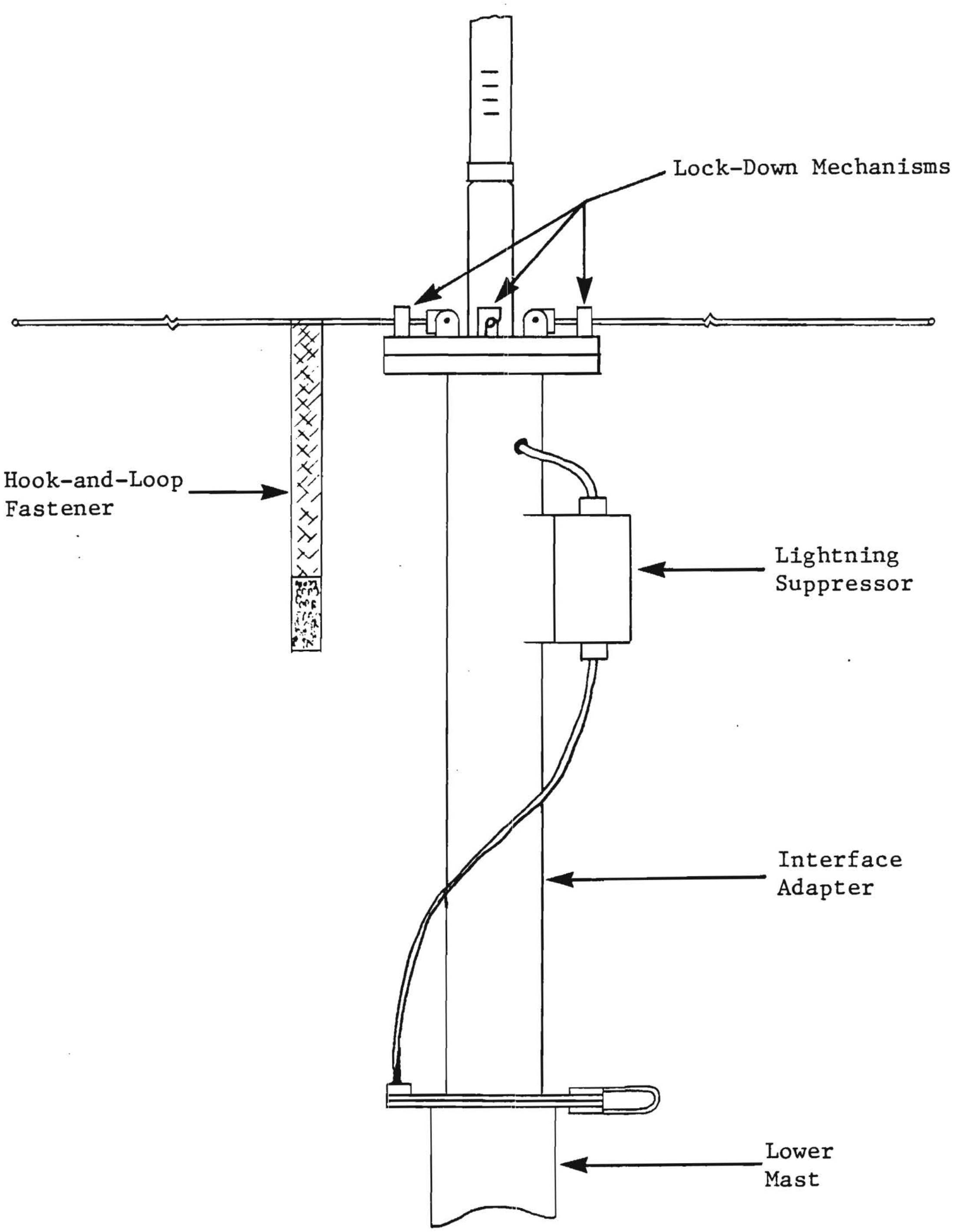

Figure B-2. Conceptual Design of Interface Adapter.

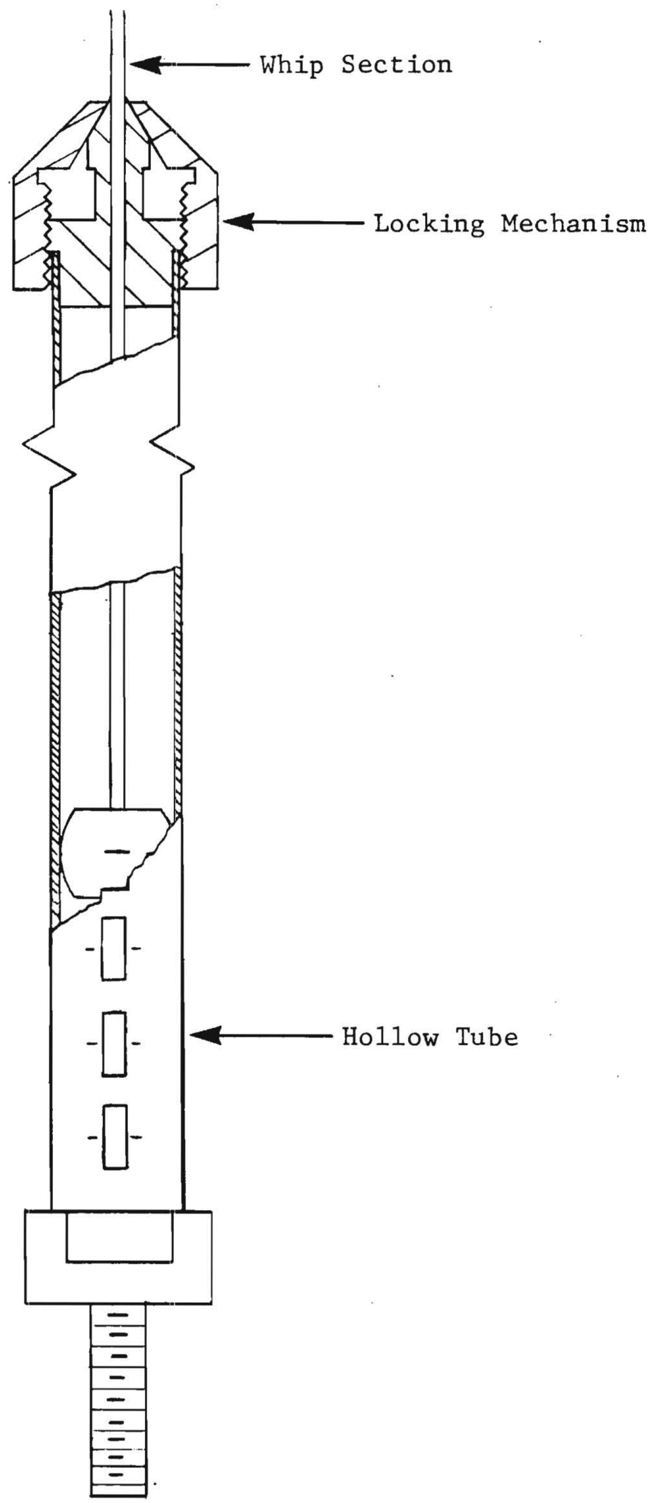

Figure B-3. Conceptual Design of the Adjustable Radiating Element.

APPENDIX C

Electrical Measurements to Support Mechanical Design

The objective of the antenna measurements was to obtain information necessary to determine the mechanical requirements and constraints for the prototype antenna. The electrical measurements performed under this Work Order were an extension of those performed under Delivery Order No. 0063 issued under Contract DAAH01-81-D-A003. Specifically, measurements were performed to: (1) determine if a fixed ground radial length could be used to cover the frequency range of interest and, if so, what the optimum length of these radials should be, (2) determine if interchanging "off-the-shelf" base-loading coils has any effect on the antenna performance, and (3) experimentally verify that a zero degree ground radial decline angle will improve the gain characteristics of the antenna as was analytically predicted under Delivery Order No. 0063. The results of these measurements were used to validate the feasibility of the proposed antenna system and to determine the mechanical requirements of the antenna mount.

Antenna gain measurements were made at 68, 79, and 88 MHz using the test method and configuration described in the Georgia Tech final report[1] under the previous delivery order. Once again, it should be noted that these measurements were performed at zero degrees elevation angle relative to horizontal with the antenna-under-test mounted in its normal operating orientation (i.e., vertical), and therefore the measured gain is not necessarily the maximum gain in the elevation plane.

The radiating element was tuned to be 5/8-wavelength long at each test frequency and was base-loaded for impedance matching. The antenna utilized three (3) ground radials (determined to be the optimum number from measurements made during the previous delivery order) and the length and decline angle of these radials were adjusted using the procedures detailed in the previously referenced report. Decreasing the decline angle from 15 degrees to zero degrees resulted in a 1.1 dB improvement in gain using 36-inch ground radials at 79 MHz. It was therefore concluded that a zero degree decline angle should be used in the prototype antenna design. It was also determined that interchanging the base-loading coil of the original monopole, which was tuned to 88 MHz, with the base-loading coil from a monopole antenna tuned to 78 MHz, had no discernable effect on the gain characteristics at

[1] J. A. Woody, "Evaluation of Proposed Antenna and Selected Modifications," Contract No. DAAH01-81-D-A003, Delivery Order No. 0063, March 1983.

79 MHz. And finally, the antenna gain was monitored while varying the ground radial length from 24 inches to 48 inches for each of the three test frequencies (68, 79, and 88 MHz). It was concluded that 34 to 36 inches is the optimum range for the radial length so that no degradation in antenna gain occurs over the entire 68 to 88 MHz frequency range. A length of 36 inches will be used in order to obtain a marginal amount of additional isolation from metallic objects located beneath the antenna.